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(54) **Tuned entrance fang configuration for ink-jet printers**

(57) A thermal ink-jet pen which includes a tuned printhead for ejecting droplets of ink onto a print medium is provided. The printhead comprises (a) a plurality of resistive elements (12), (b) a plurality of nozzles through which the droplets of ink are ejected, (c) a plurality of drop ejection chambers, (d) a plurality of ink feed channels, each provided with an entrance defined by a pair of projections on either side thereof, and (e) an ink refill slot (16) operatively associated with the plurality of ink feed channels, the ink refill slot (16) defined by an edge (16a) to provide a shelf from the edge (16a) to the ink feed channels. The plurality of resistive elements (12) is divided into sets, with each resistive element (12) staggered a different distance from the edge (16a). Each ink feed channel within a set is provided with a different critical dimension value, the critical dimension comprising at least one selected from the group consisting of (1) width of entrance to channel, (2) width of the channel, (3) length of the channel, and (4) distance of the resistive element (12) to the terminus of the channel. The critical dimension is related to distance of the resistive element (12) from the edge (16a). By providing each set of resistive elements (12) with different widths, the damping of the pen is improved and all the nozzles have substantially the same refill speed.

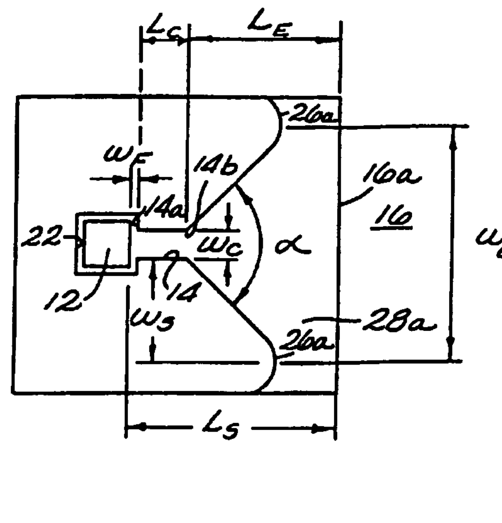


FIG. 3

EP 0 691 204 A1

Description

TECHNICAL FIELD

The present invention relates generally to ink-jet pens employed in thermal ink-jet printers, and, more particularly, to an improved printhead structure for introducing ink into the firing chambers from which the ink is ejected onto the print medium. The improved printhead structure improves damping of the pen, permitting all chambers to have substantially the same refill speed.

BACKGROUND ART

In the art of thermal ink-jet printing, it is known to provide a plurality of electrically resistive elements on a common substrate for the purpose of heating a corresponding plurality of ink volumes contained in adjacent ink reservoirs leading to the ink ejection and printing process. Using such an arrangement, the adjacent ink reservoirs are typically provided as cavities in a barrier layer attached to the substrate for properly isolating mechanical energy to predefined volumes of ink. The mechanical energy results from the conversion of electrical energy supplied to the resistive elements which creates a rapidly expanding vapor bubble in the ink above the resistive elements. Also, a plurality of ink ejection orifices are provided above these cavities in a nozzle plate and provide exit paths for ink during the printing process.

In the operation of thermal ink-jet printheads, it is necessary to provide a flow of ink to the thermal, or resistive, element causing ink drop ejection. This has been accomplished by manufacturing ink refill channels, or slots, in the substrate, ink barrier, or nozzle plate.

Current thermal ink-jet pen designs utilize a resistor multiplex pattern which allows the resistors to be "fired" at different times. Therefore, the resistors are offset spatially to compensate for this timing. These pens are fabricated by cutting the ink refill slot through a silicon substrate, which provides a vertical edge, or shelf, perpendicular to the print swath, while the resistors are staggered with respect to this edge, thereby creating different path lengths from the ink source or fill slot for each resistor.

The consequence of this design is that the entrance length (the distance from the edge of the shelf to the channel entrance on an individual chamber basis) varies from 61 µm to 94 µm, with the nominal shelf length of 125 µm on one particular commercial thermal ink-jet pen. Currently, all chambers have a 90° tapered fang residing between the slot and the channel. The line width frequency testing has shown that the refill speed varies between chambers, with the 61 µm entrance length producing a "faster" chamber than the 94 µm entrance length. Specifically, the nozzles with shortest entrance lengths are 350 Hz faster than those furthest from the slot.

The different path lengths offer varying resistance to ink flow and thus vary the time it takes to refill each resistor firing chamber. The chamber cannot be fired in a predictable manner until refill takes place. In addition, these varying resistances vary the damping of the chamber. If a chamber is over-damped, it is a slower structure than optimum and if under-damped, can cause nozzle instability resulting in spray, etc.

One possible solution is to etch the silicon shelf leading up to the inlet channel; see, e.g., Serial No. 08/009,151 and Serial No. 08/009,181, both filed January 25, 1993, and assigned to the same assignee as the present application. While that solution certainly provides a satisfactory result, it is nonetheless a costly process step.

Thus, there is a need to provide a mechanism for permitting all chambers to have the same refill speed, regardless of entrance length.

DISCLOSURE OF INVENTION

In accordance with the invention, each individual chamber is optimally tuned by varying one or more critical dimensions in the ink flow path, depending on distance of the resistor from the edge of the ink refill slot. The critical dimension may be any of the following: the width of the entrance to the ink feed channel, the width of the ink feed channel, the length of the ink feed channel, and/or the distance of the resistor to the terminus of the channel.

In the first embodiment (width of entrance to the ink feed channel), for example, chambers close to the ink refill slot have comparatively smaller channel openings, whereas those further away from the ink refill slot have comparatively wider openings. The chambers with the longest entrance lengths will use the largest width, while those with the shortest entrance length will use the smallest width. The only change required to the existing thermal ink jet pen design is the barrier mask. By so altering the widths, the damping of the pen is improved. Tuning the widths to compensate for the resistor multiplex pattern allows for all the nozzles to have the same refill speed.

In each of these embodiments, by tuning the indicated critical dimension with respect to the distance from the nozzle to the shelf, the impedance of all chambers can be balanced so as to provide substantially the same refill speed for all nozzles. These approaches all result in improved damping of the pen.

As an example, by reducing the widths (either entrance or channel) of certain nozzles, then nozzle-to-nozzle frequency variation can be reduced. As indicated above, the widths of the nozzles closest to the slot are considerably

narrower than the prior art design, while those furthest away are essentially unchanged. As a result, the difference (frequency variation) between the closest and furthest nozzles is reduced from 350 Hz (prior art design) to only 50 Hz.

The thermal ink-jet pen of the present invention includes elements common to prior art pens, such as a printhead for ejecting droplets of ink onto a print medium, the printhead comprising (a) a plurality of resistive elements for heating ink supplied from a reservoir to generate the droplets of ink, (b) a plurality of nozzles through which the droplets of ink are ejected, with one nozzle associated with one resistive element, (c) a plurality of drop ejection chambers, each chamber enclosed on three sides by a barrier, each chamber having a floor supporting the resistive element, with the nozzle supported above the resistive element by said barrier, (d) a plurality of ink feed channels, each for supplying ink to one of the drop ejection chambers, and each ink feed channel provided with an entrance defined by a pair of projections on either side thereof, and (e) an ink refill slot operatively associated with the plurality of ink feed channels, the ink refill slot defined by an edge to provide a shelf from the edge to the entrances to the ink feed channels. The plurality of resistive elements is divided into sets, with a constant number of resistive elements per set, with each resistive element staggered a different distance from the edge. Each ink feed channel is provided with at least one different critical dimension (width of ink feed channel entrance, width of ink feed channel, length of ink feed channel, distance of resistor to the terminus of the channel. The width (en-trance or channel) of the resistive element that is closer to the edge is narrower than the width of the resistive element that is further from the edge. The length of the channel of the resistive element that is closer to the edge is longer than the length of the channel of the resistive element that is further from the edge. The distance of resistor to the terminus of the channel for the resistive element that is closer to the edge is larger than that of the resistive element that is further from the edge.

The tuned critical dimensions of the present invention allows optimization of the architecture across the pen, allowing all nozzles to operate at an optimum damping factor, which in turn causes less ink spray and more uniform printing.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view, depicting a single resistor element and associated components in a thermal ink-jet pen;

FIG. 2 is a top plan view of a plurality of such resistor elements, comprising a portion of a printhead in the pen of FIG. 1;

FIG. 3 is a top plan view of one resistor element, for definitional purposes;

FIG. 4, on coordinates of frequency (in Hertz) and distance (in µm), is a plot of the maximum operating frequency as a function of the distance between the edge of the shelf and the channel entrance for a prior art design;

FIG. 5 is a top plan view of a quartet of resistor elements, employing a design in accordance with the present invention in which the width of the entrance to the ink feed channel is varied as a function of shelf length;

FIG. 6, on coordinates of frequency (in Hertz) and distance (in µm), is a plot similar to that of FIG. 4, but based on the design depicted in FIG. 5; and

FIG. 7 is a top plan view of a portion of a printhead, depicting an alternate embodiment of the present invention, in which the width of the ink feed channel is varied as a function of shelf length.

BEST MODES FOR CARRYING OUT THE INVENTION

Referring now to the drawings wherein like elements of reference designate like elements throughout, a single resistor element **10** is shown in FIG. 1, comprising a resistor **12** situated at one end **14a** of an ink feed channel **14**. Ink (not shown) is introduced at the opposite end **14b** thereof, as indicated by arrow "**A**", from a plenum, or ink refill slot, indicated generally at **16**. Associated with the resistor is a nozzle **18**, located above the resistor **12** in a nozzle plate **20**. The resistor **12** is energized by means not shown to fire a bubble of ink through the nozzle (i.e., normal to the surface of the resistor).

The resistor **12** is located in a firing chamber **22** at the terminus **14a** of the ink feed channel **14**. Both the chamber **22** and the ink feed channel **14** are formed in a barrier material **24**, which advantageously comprises a photoresist material. The photoresist material is processed, using conventional photolithographic techniques, to define the chamber **22** and ink feed channel **14**.

Fangs, or lead-in lobes, **26**, one on each side of the entrance to the ink feed channel **14**, serve to prevent bubbles in the ink from residing in the ink refill slot area and act to guide any such bubbles into the firing chamber **22**, where they are purged during firing of the resistor **12**. The fangs terminate in fang tips **26a**. Such fangs are disclosed and claimed in U.S. Patent 4,882,595, assigned to the same assignee as the present application.

A plurality of such resistors **12** and associated nozzles **18** are used to form a printhead. FIG. 2 depicts a prior art pen design, in which two rows of a plurality of resistors **12** are provided, one on either side of the ink refill slot **16**. In this prior art design, all resistors **12** are staggered a different distance from the ink refill slot **16**, yet are supplied with ink from a common source of ink. While not shown in FIG. 2, the fang tips **26a** are also staggered from the ink refill slot **16** in the prior art design.

FIG. 3 provides a visual description of terms employed in this application. Entrance length L_E is the distance from the edge **16a** of the ink refill slot **16** to the beginning of the ink feed channel **14**. Shelf length L_S is the distance from the resistor **12** to the edge **16a** of the shelf **28a**. Entrance width W_E is measured between fang tips **26a**, while channel width W_C is the width of the ink feed channel **14** itself, as defined by the walls of the barrier **24**. Channel length L_C is the length of the ink feed channel **14**, from its channel entrance **14b** to its terminus **14a**. Distance W_F is the distance from the resistor **12** to the entrance to the resistor chamber **22**, defined by the terminus **14a** of the channel **14**, also called the "front wall". The included angle α is relative to the edges of the fangs **26**. Shelf **28a** refers to the top of the substrate **28** exposed by removal of the barrier material **24** in defining the fangs **26** and other features of the resistor element **10**.

Assuming a constant shelf length L_S, there are four parameters, or critical dimensions, that can be varied in accordance with the present invention to tune all nozzles in the pen to operate at an optimum damping factor. These parameters include varying the channel entrance width W_E, the channel width W_C, the channel length L_E, and the resistor-to-front wall distance W_F. One or more of these parameters may be varied to provide the optimum damping factor. Tuning of each of these parameters is discussed in further detail below.

<u>Tuning by Varying Channel Entrance Width W_E</u>:

It is instructive to examine prior art solutions to chamber refill and damping in thermal ink-jet pen designs. The previous (default) approach has a constant 90° entrance angle and lets the fang tips fall as they may. FIGs. 1 and 2 illustrate this approach, showing a plurality of firing chambers, each a different distance from the edge of the ink refill slot **16**, thereby providing a different entrance length L_E. These prior art pen designs employ a repeating pattern of 13 staggered firing chambers **22**.

One of the first observations of testing such pens as shown in FIG. 2 was that the maximum operating frequency of individual nozzles tended to follow the nozzle stagger pattern. Without subscribing to any particular theory, the following hypothesis was developed: Since the nozzles closest to the ink refill slot **16a** (thus, reduced entrance length L_E) have less entrained mass and lower viscous drag than the nozzles furthest away, then the nozzles closest to the ink refill slot **16** can refill quicker. As a first attempt at using the entrance area to compensate for nozzle-to-nozzle variation, a laminar flow spreadsheet model was developed. Although this model was in no means a complete analysis, it did show the feasibility of tuning the entrances. Subsequently, it became possible to predict that refill rate was correlated to both entrance length L_E and width W_E (these terms are shown in FIG. 3).

The theory behind this approach was that the nozzles which reside closest to the ink refill slot **16** (and thus have the shortest entrance length L_E) could be slowed down by narrowing their entrance widths W_E, while those furthest away would remain essentially unchanged. A barrier matrix mask was designed with four tuned entrance designs as well as the default prior art design. After the pens were built, they were measured using a linewidth frequency response technique.

The default, or prior art, pen design was included in this study for comparison purposes. As shown in FIG. 2, the default design has a constant 90° included angle on all of the entrances. Leveraging previous experiments on this family of pens, the nozzles closest to the ink refill slot **16** were expected to be faster than those furthest away. FIG. 2 illustrates that there is a constant 90° included angle on all of the default prior art entrances, regardless of entrance length L_E.

Using the linewidth frequency response measurement technique, data was collected for individual nozzle response. Displayed in FIG. 4, the nozzles closest to the ink refill slot **16** were faster than those furthest away. The squares in the Figure denote average values; the vertical bars denote 95% confidence levels.

As mentioned previously, this work was based on the idea that the nozzles closest to the slot could be restricted by narrowing their entrance widths W_E, while those furthest away would remain essentially unchanged. The concept was that all nozzles would have the same refill rates as the slowest nozzles. Since this would result in a lower average frequency of the pen, these designs were built with both the default 1 mil and thicker 1.1 mil barrier **24** to preserve operating speed. According to the computational modeling results, the tuned entrance design of the present invention, shown in FIG. 5, was determined to be the most likely candidate for success. In FIG. 5, the nozzle at the upper portion of the Figure has the longest entrance length L_E. However, the nozzle closest to the slot (at the lower portion) has a considerably narrower entrance width W_E than the default design shown in FIG. 2.

Data was again gathered for individual nozzle response using linewidth frequency response measurement. As shown in FIG. 6, the difference in maximum operating frequency between the nozzles closest to the shelf and those furthest away was considerably less than the default design. The slope of the line is considerably less than for the default design (shown in FIG. 2). The squares and vertical bars have the same meaning as in FIG. 4.

The results shown in FIG. 6 indicate that there was still some nozzle-to-nozzle variation present in even the most optimistic design. Nevertheless, the matrix mask included a large experimental design space. By analyzing individual nozzles for maximum operating frequency (in Hertz) as a function of barrier thickness **t** (measured in mils), entrance length L_E (measured in µm), and entrance width W_E (measured in µm), a 0.97 correlation coefficient was found:

$$\text{Frequency} = 23300{*}t - 91.2{*}L_E + 32.1{*}W_E - 13800.$$

Using this formula, a fully populated tuned entrance barrier mask for the pen has been designed.

Although the present work examined only a particular pen design, tuned entrances can be applied to any of the slot-feed pen designs. Since this concept minimizes nozzle-to-nozzle variation without changing resistor, orifice, or channel dimensions, adaptation is expected to be relatively straight forward. The aforementioned formula can be reduced as follows:

$$W_E = 2.84 * L_E + \text{Constant.}$$

In order to determine the value of the constant, one inputs the default dimensions of the nozzle furthest from the slot. For the particular pen configuration discussed herein, these values are 82 µm long by 198 µm wide, which yields a constant of -35 µm. To find desired entrance widths for the other nozzles, all that is required is to insert their entrance lengths in the reduced formula above. As an example, the first nozzle of the set of nozzles in the particular pen configuration discussed herein has an entrance length of 57 µm and thus 2.84*57 - 35 = 127, which thus provides an entrance width of 127 µm on the fully populated barrier mask.

In some pen designs, there simply is not enough real-estate in between the nozzles to implement tuned entrances. There are three alternatives to compensate for nozzle-to-nozzle variation, which are now discussed.

<u>Tuning by Varying Channel Width W_C:</u>

In the second embodiment, the channel width can be varied. Nozzles closest to the shelf should have narrower channel widths W_C than those furthest away. For a maximum shelf length of 130 µm, the channel width is preferably given by

$$W_C = 0.7222 * L_S - 42.89,$$

while for a maximum shelf length of 160 µm, the channel width is preferably given by

$$W_C = 0.7222 * L_S - 64.56.$$

In this embodiment, the width W_C of the ink feed channel itself is varied. FIG. 7 depicts the tuned configuration for a set of three staggered resistor elements.

Since refill time varies as a result of the nozzle offset for multiplexing nozzle firing, tuning is accomplished by providing different widths of the ink feed channels. Specifically, longer channels have wider spacing.
The relationship between refill time t_R and channel length L_C and channel width W_C is given by

$$t_R \propto L_C / W_C.$$

<u>Tuning by Varying Channel Length L_C:</u>

In addition to the previous compensation methods, channel length L_C can also be used to remove nozzle-to-nozzle variations. Longer channels produce slower chambers. Thus, nozzles closest to the shelf have long channels, while those further away should have short channels. For a maximum shelf length of 130 µm, the channel length is preferably given by

$$L_C = -0.7222 * L_S + 97.89,$$

while for a maximum shelf length of 160 µm, the channel length is preferably given by

$$L_C = -0.8056 * L_S + 132.9.$$

<u>Tuning by Varying Front Wall Distance W_F:</u>

Yet another alternative to balancing the impedance of the various chambers is to change the front wall distance W_F. According to modeling and thermal ink-jet history, a large front wall produces a slower nozzle. Therefore, by having a large front wall on the nozzles closest to the shelf, and a small front wall on those furthest away, the chambers will have minimal refill variation. For a shelf length of 130 µm and front wall distance W_F values ranging from 8 to 34 µm, the front wall distance is preferably given by

$$W_F = -0.7222 * L_S + 101.9,$$

while for a shelf length of 160 μm and front wall distance, W_F values ranging from 8 to 64 μm, the front wall distance is preferably given by

$$W_F = -1.556 {}^* L_S + 256.9.$$

In another alternative and using modeling data, sets of resistors **12**, comprising 22 resistors per set, were designed in which the distance from the resistor to the front wall, W_F, varied from 8 to 75.75 μm. The shelf length L_S varied from 160 μm (at a front wall distance of 8 μm) to 123.75 (at a front wall distance of 75.75 μm). The following relation was developed to provide an essentially zero variation in refill frequency:

$$W_F = -1.865 {}^* L_S + \text{Constant}.$$

For the particular pen design discussed above, the value of the constant is 306.5.

The model predicts a variation in refill frequency of about 3 kHz (for a nominally 8 kHz pen) where the first wall distance W_F is kept constant at 8 μm and the shelf length L_S is 130 μm.

EXAMPLES

Examples 1-12:

Computer modeling results were run to determine the effects of varying one or two critical dimensions while holding other critical dimensions constant. Examples 1-6 are directed to a pen design having a maximum shelf length of 130 μm, while Examples 7-12 are directed to a pen design having a maximum shelf length of 160 μm.

In each case, the maximum and minimum shelf length L_S are listed, along with the corresponding channel width W_C, the front wall distance W_F, and the channel length L_C. The dimensions are in units of μm. The resulting pen refill frequency **f**, in Hertz, is listed for each case.

Maximum Shelf of 130 μm.

Example 1: No Compensation

L_S	W_C	W_F	L_C	f
94	25	8	4	16,095
130	25	8	4	8,667

Example 2: Channel Width Compensation

L_s	W_c	W_F	L_c	f
94	25	8	4	16,095
130	51	8	4	9,358

$$W_c = 0.7222 * L_s - 42.89$$

Example 3: Front Wall Compensation

L_s	W_c	W_F	L_c	f
94	25	34	4	13,043
130	25	8	4	8,667

$$W_F = -0.7222 * L_s + 101.9$$

Example 4: Channel Length Compensation

L_s	W_c	W_F	L_c	f
94	25	8	30	9,394
130	25	8	4	8,667

$$L_c = -0.7222 * L_s + 97.89$$

Example 5: Channel Width and Front Wall Compensation

L_S	W_C	W_F	L_C	f
94	25	34	4	13,043
130	51	8	4	9,358

Example 6: Channel Width and Channel Length Compensation

L_S	W_C	W_F	L_C	f
94	25	8	30	9,394
130	51	8	4	9,358

Maximum Shelf Length of 160 µm.

Example 7: No Compensation

L_S	W_C	W_F	L_C	f
124	25	8	4	9,389
160	25	8	4	6,260

Example 8: Channel Width Compensation

L_S	W_C	W_F	L_C	f
124	25	8	4	9,389
160	51	8	4	7,042

$$W_c = 0.7222*L_s - 64.56$$

Example 9: Front Wall Compensation

L_S	W_C	W_F	L_C	f
124	25	64	4	7,575
160	25	8	4	6,260

$$W_F = -1.556*L_s + 256.9$$

Example 10: Channel Length Compensation

L_S	W_C	W_F	L_C	f
124	25	8	33	6,244
160	25	8	4	6,260

$$L_c = -0.8056*L_s + 132.9$$

Example 11: Channel Width and Front Wall Compensation

L_S	W_C	W_F	L_C	f
124	25	64	4	7,575
160	51	8	4	7,042

Example 12: Channel Width and Channel Length Compensation

L_S	W_C	W_F	L_C	f
124	25	8	23	7,060
160	51	8	4	7,042

From the foregoing results, it is clear that varying at least one of the critical dimensions improves the pen performance by reducing the difference in refill frequency between the two shelf lengths listed. Varying two of the critical dimensions provides even further improvement.

Examples 13-14:

The effect of channel width on nozzle frequency is shown in the Table below for two resistor sizes, 52 µm and 55 µm. Local refill refers to the frequency at which one nozzle firing will refill with ink, while global refill refers to the frequency at which all nozzles firing will refill with ink.

Example 13:

Resistor Size	Channel Width	Local Refill	Global Refill
52 µm	30 µm	6200 Hz	5200 Hz
52 µm	40 µm	6300 Hz	5350 Hz
52 µm	50 µm	6400 Hz	5450 Hz

Example 14:

Resistor Size	Channel Width	Local Refill	Global Refill
55 µm	30 µm	5500 Hz	4650 Hz
55 µm	40 µm	5900 Hz	4700 Hz
55 µm	50 µm	6100 Hz	4750 Hz

It will be seen that for a resistor size of 52 µm, the nozzle frequency is substantially constant for all channel widths. This Table also shows for a larger resistor, more ink is ejected, resulting in a lower frequency response to refill the chamber. Further, for the larger resistor, the channel width has more of an effect on the refill frequency.

INDUSTRIAL APPLICABILITY

The tuned entrance fang configuration of the present invention is expected to find use in future thermal ink-jet printers.

Thus, there has been disclosed a tuned entrance fang configuration in thermal ink-jet printheads. It will be readily apparent to those skilled in this art that various changes and modifications of an obvious nature may be made, and all

such changes and modifications are considered to fall within the scope of the invention, as defined by the appended claims.

Claims

1. A thermal ink-jet pen including a printhead for ejecting droplets of ink onto a print medium, said printhead comprising (a) a plurality of resistive elements for heating ink supplied from a reservoir to generate said droplets of ink, (b) a plurality of nozzles through which said droplets of ink are ejected, with one nozzle associated with one resistive element, (c) a plurality of drop ejection chambers, each chamber enclosed on three sides by a barrier, each chamber having a floor supporting said resistive element, with said nozzle supported above said resistive element by said barrier, (d) a plurality of ink feed channels, each for supplying ink to one said drop ejection chamber through an entrance on a fourth side of said chamber, and each ink feed channel provided with a channel entrance defined by a pair of projections on either side thereof, and (e) an ink refill slot operatively associated with said plurality of ink feed channels, said ink refill slot defined by an edge to provide a shelf from said edge to said plurality of ink feed channels, wherein said plurality of resistive elements is divided into sets, with each resistive element staggered a different distance from said edge, wherein each ink feed channel within a set is provided with a different critical dimension value, said critical dimension comprising at least one selected from the group consisting of (1) width of said entrance to said channel, (2) width of said channel, (3) length of said channel, and (4) distance of said resistive element to said entrance to said fourth side of said chamber, and wherein said critical dimension is related to distance of said resistive element from said edge.

2. A thermal ink-jet pen according to claim 1 wherein said width of said channel entrance is measured between projections defining a particular ink feed channel.

3. A thermal ink-jet pen according to claim 1 or 2 wherein said resistive elements comparatively closer to said edge have a narrower width of said channel entrance to said ink feed channel than resistive elements comparatively further from said edge.

4. A thermal ink-jet pen according to any of claims 1 to 3 wherein said pen operates at a frequency given by the following equation:

$$f = 23300^*t - 91.2^*L_E + 32.1^*W_E - 13800,$$

where t is thickness of said barrier, L_E is said distance from said shelf to said channel entrance of said ink feed chamber, and W_E is said width of said entrance to said ink feed channel.

5. A thermal ink-jet pen according to claim 1 wherein said width of said channel is measured between walls of said barrier defining a particular ink feed channel.

6. A thermal ink-jet pen according to claim 5 wherein said resistive elements comparatively closer to said edge have a narrower width of said channel than resistive elements comparatively further from said edge.

7. A thermal ink-jet pen according to any preceding claim wherein said length of said channel is measured along a wall of said barrier defining a particular ink feed channel.

8. A thermal ink-jet pen according to claim 7 wherein said resistive elements comparatively closer to said edge have a longer length of said channel than resistive elements comparatively further from said edge.

9. A thermal ink-jet pen according to any preceding claim wherein said distance of said resistive element to said fourth side of said chamber is measured from an edge of said resistive element closest to said fourth side of said chamber.

10. A thermal ink-jet pen according to claim 9 wherein said distance of said resistive element to said fourth side of said chamber, W_F , is given by:

$$W_F = -0.7222^*L_S + \text{Constant},$$

where L_S is said distance of said resistive element to said edge of said ink refill slot.

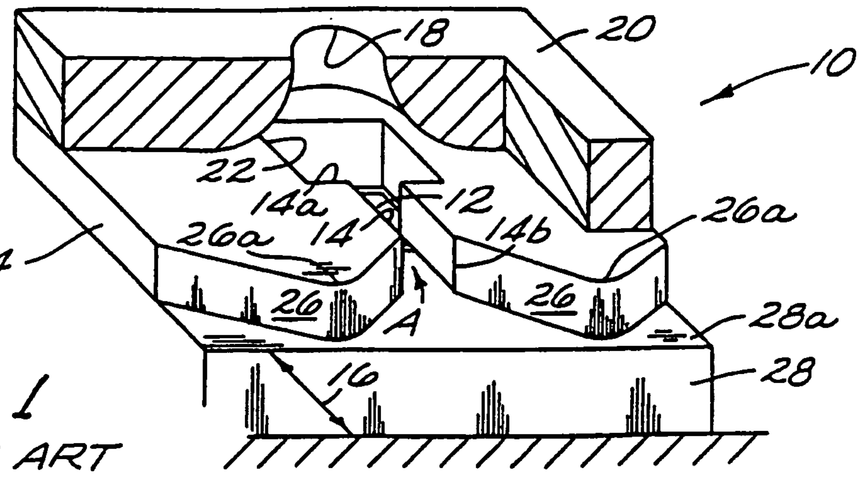


FIG. 1
PRIOR ART

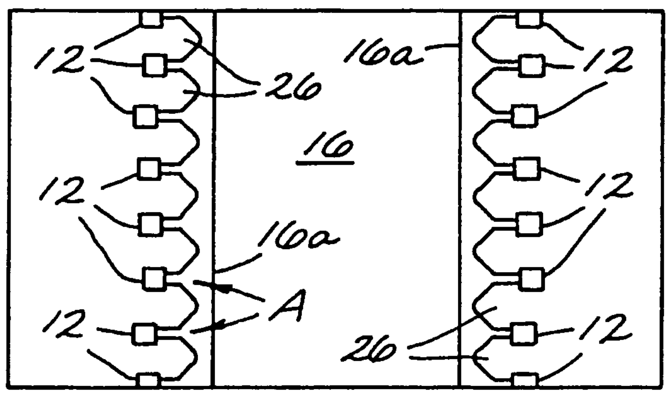


FIG. 2
PRIOR ART

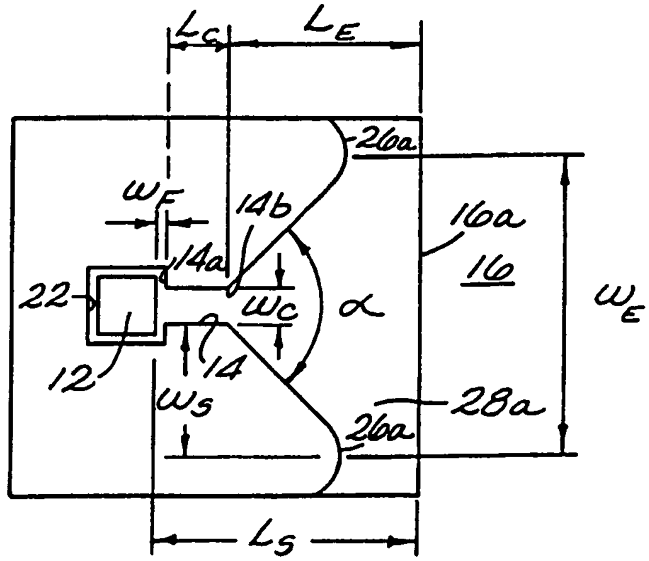


FIG. 3

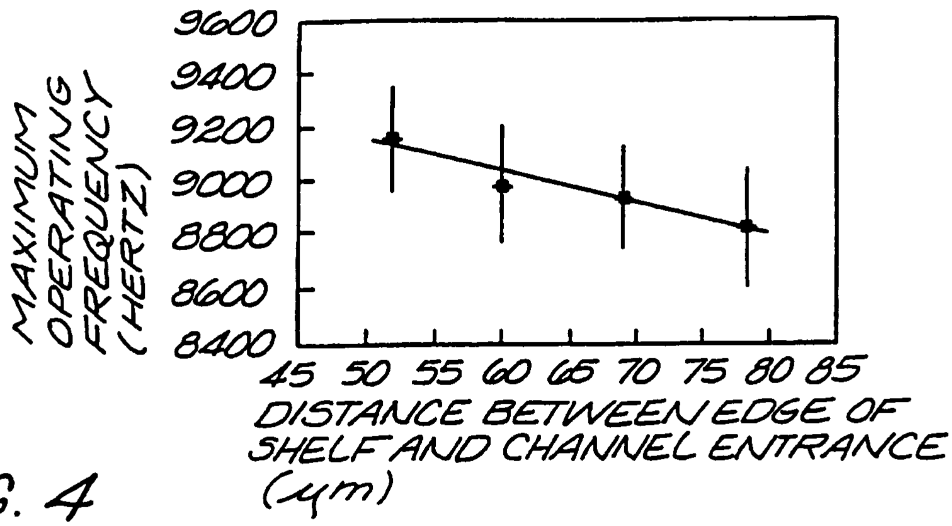

MAXIMUM OPERATING FREQUENCY (HERTZ)
9600
9400
9200
9000
8800
8600
8400
45 50 55 60 65 70 75 80 85
DISTANCE BETWEEN EDGE OF SHELF AND CHANNEL ENTRANCE (μm)

FIG. 4

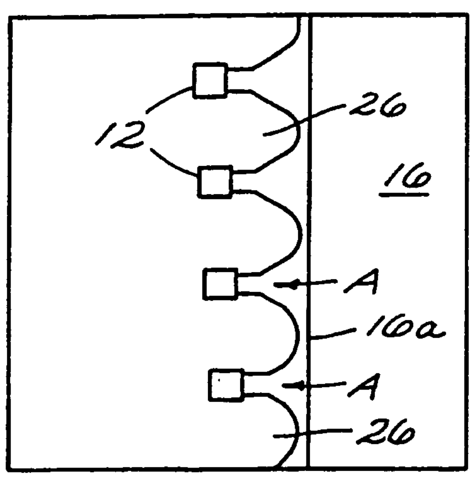
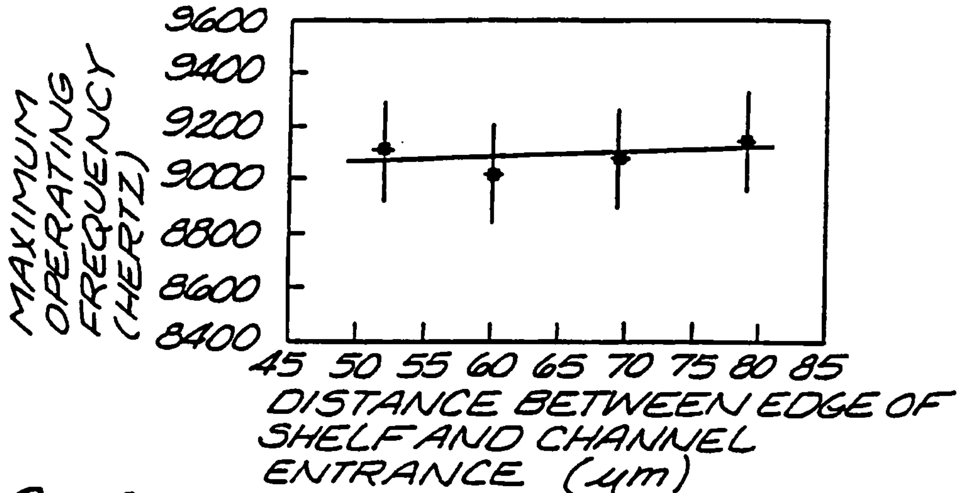
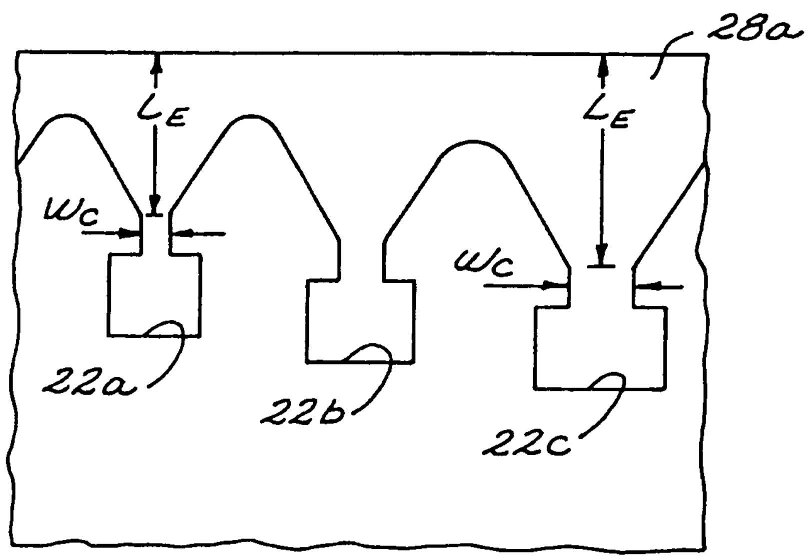

12
26
16
A
16a
A
26

FIG. 5



9600
9400
9200
9000
8800
8600
8400
MAXIMUM OPERATING FREQUENCY (HERTZ)
45 50 55 60 65 70 75 80 85
DISTANCE BETWEEN EDGE OF SHELF AND CHANNEL ENTRANCE (μm)

FIG. 6



28a
L_E
L_E
W_C
W_C
22a
22b
22c

FIG. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 95 30 2309

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	EP,A,0 577 383 (HEWLETT-PACKARD COMP.) * abstract; figures 1-4 * ---	1	B41J2/14
A	EP,A,0 568 247 (HEWLETT-PACKARD COMP.) * abstract; figure 3 * ---	1	
A	EP,A,0 439 633 (SIEMENS A.G.) * abstract; figure 4 * ---	1	
A	EP,A,0 314 486 (HEWLETT-PACKARD COMP.) * abstract; figures 3A,C,6 * ---	1	
A	US,A,4 882 595 (K.E. TRUEBA ET AL.) cited in the application ---		
A	US,A,5 308 442 (H.H. TAUB ET AL.) cited in the application * figures 1-3 * -----	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			B41J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
BERLIN	15 June 1995	Zopf, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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& : member of the same patent family, corresponding document